

Influence of grazing on populations of the specialist grasshopper *Mioscirtus wagneri* inhabiting hypersaline habitats in La Mancha Region, Central Spain

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Abstract

Grazing is an influential land use that has introduced profound changes in worldwide landscapes, ecosystems and their species. In this paper, we analysed the influence of grazing on the presence and abundance of the endangered *Mioscirtus wagneri*, a monophagous grasshopper inhabiting inland hypersaline ecosystems in Spain and showing a marked spatial and genetic fragmentation. Using count transects, we analyzed the presence and abundance of this grasshopper in relation to specific vegetation cover and the abundance of goat and sheep droppings, considering this variable as a surrogate of livestock activity and grazing impact. We found that both the presence and abundance of *M. wagneri* were positively related to the cover of its host plant *Suaeda vera* and negatively associated with the abundance of droppings. We conclude that dropping abundance is a useful parameter to assess livestock impact and evaluate habitat quality and the conservation status of *M. wagneri* and many other singular species of macroinvertebrates inhabiting inland hypersaline ecosystems. We highly recommend the use of electric shepherd fencing around all sensitive and protected areas where inland hypersaline ecosystems are present in order to deter livestock. We also suggest intensive educational campaigns for farmers and shepherds, revealing the ecological importance of these singular and unique habitats for rare and exclusive species like *M. wagneri* and many other coexisting plants and invertebrates.

Key words

Castilla-La Mancha, conservation, grazing management, inland hypersaline ecosystems, livestock droppings, *Suaeda vera*

Introduction

Historical and current grazing activities are an important influence on the landscape and, thus, on plant and animal community composition (González Bernáldez 1981, Blondel and Aronson 1999). However, intense grazing activities may alter the soil, exerting a negative impact on species biodiversity (Fleischner 1994). Intensive browsing, trampling, and resting on the ground can have a negative impact on the vegetation cover, increasing the proportion of bare soil and aggravating the effects of periods of drought

(Ledesma 2000, Gardiner and Haines 2008). However, other studies have found an opposite effect (Kisbenedek 1995, Pocco et al. 2010). In fact, grazing activities can have opposite effects on the biodiversity of both plant and animal communities depending on grazing management, intensity and the characteristics of the affected area (e.g. Rook and Tallowin 2003, Cingolani et al. 2005, Branson et al. 2006, Debano 2006, Dumont et al. 2009, Krausman et al. 2009, Baldi et al. 2013). Grazing contributes to habitat heterogeneity for Orthoptera when moderate (Fartmann et al. 2012). However, the influence of grazing on the abundance of orthopterans varies with grazing management and season (Gebeyehu and Samways 2003). Different studies have found that rotational grazing may be beneficial for orthopteran communities whereas total absence of grazing may be negative for orthopteran populations in other cases (Gebeyehu and Samways 2003, Fonderflick et al. 2014). It is worth mentioning that within a particular area, grazing may also have positive or negative effects on orthopteran populations depending on the species (Jepson-Innes and Bock 1989, Fielding and Brusven 1995, O'Neill et al. 2003).

To test the impact of grazing on grasshopper abundance, we focused on the populations of a specialist species, *Mioscirtus wagneri* (Kittary, 1859) (Orthoptera: Acrididae) inhabiting continental hypersaline habitats both around hypersaline lagoons and in salted ground prairies of the plant association *Suadetum brevifoliae* (Cirujano-Bracamonte 1981). The species feeds and obtains shelter from alkali seepweed (*Suaeda vera*) bushes (Cordero et al. 2007b, Ortego et al. 2010). Because of its specialized host plant dependence, we predict that grazing has a profound impact on the habitat of *M. wagneri* and provokes a significant negative effect on its populations.

Here, we aim to provide information on threats related to livestock activity on *M. wagneri* and its sensitive and exclusive hypersaline habitat. The aim of this study is to determine, 1) the association of *M. wagneri* with its host plant (*S. vera*, alkali seepweed) and 2) how grazing activity is related to the presence and abundance of this grasshopper in two localities, including grazed and ungrazed plots around hypersaline lagoons of La Mancha Region (Central

Spain). To attain this, we analysed the relationship between the abundance and presence of *M. wagneri* obtained from count transects and the cover of different species of plants, the type of soil, and the abundance of livestock droppings, used as a surrogate of the intensity of livestock activity.

Methods

Study area.—The study area includes two inland salted lagoons in the center of Iberian Peninsula: Peña Hueca ($3^{\circ}20'29''\text{W}$, $39^{\circ}30'50''\text{N}$) and Tirez ($3^{\circ}21'27''\text{W}$, $39^{\circ}32'21''\text{N}$) (Villacañas, Toledo Province, Central Spain) (Fig. 1). The lagoons present shallow waters, strong summer drought, and a high degree of salinity (Camacho et al. 2009). They constitute natural microreserves with karst sedimentation and endorheism (Peinado 1994). These lagoons are within the Biosphere Reserve of “La Mancha Wetlands” belonging to the European entity “LIC Wetlands of La Mancha” (Annex I of Directive 79/409 / EEC and Annex I and II of Directive 92/43 / EEC) (Bartolome et al. 2005). However, in spite of such a protection status, current legislation is not always adequate and livestock may graze, rest or pass through the protected areas around the lagoons. The halophilous vegetation present around these lagoons has been extensively studied (Cirujano-Bracamonte 1981) and is under the protection of European directives (Martín-Herrero et al. 2003). *Suaeda vera* is one of the main plant species present in these habitats, with a woody and perennial existence on saline and hypersaline soils around inland salted lagoons (Fig. 2).

The grasshopper.—The study species is *Mioscirtus wagneri*, a monophagous and specialist grasshopper with a disjunct distribution and high genetic fragmentation of its populations (Cordero et al. 2007b, Ortego et al. 2009, 2010, 2011) (Fig. 3). It has been suggested that this species is particularly sensitive to habitat destruction because of its specialist nature and strong dependence on its host plant *S. vera* (Cordero et al. 2007b, Ortego et al. 2010). *Mioscirtus wagneri* is endangered within Western Europe (Hochkirch et al. 2016). The only populations of this species in Western Europe are found in Spain. Other grasshopper species usually accompanying *M. wagneri* include *Aiolopus strepens* (Latreille, 1804), *Oedaleus decorus* (Germar, 1826), *Oedipoda charpentieri* Fieber, 1853, *Ramburiella hispanica* (Rambur, 1838), *Calephorus compressicornis* (Latreille, 1804), *Dociostaurus crassiusculus* (Pantel, 1886), *Dociostaurus jagoi occidentalis* Soltani 1978, *Calliptamus wattenwylanus* (Pantel, 1896), *Calliptamus italicus* (Linnaeus, 1758), and *Sphingonotus morini* (Defaut, 2005) (personal observation; see also Cordero et al. 2007b, Ortego et al. 2015).

Transects and variables.—To measure *M. wagneri* presence/abundance, plant species and soil type cover, we used transects in areas with different influences from grazing but within the local distribution of the grasshopper. Transects were 20 m in length, and 0.5 m on each side of the observer were surveyed (a total area of 20×1 m per transect = 20 m^2). On transects we collected data on *M. wagneri* presence and abundance, soil type, cover and species of plants and number of droppings of sheep and goats. Transects were chosen

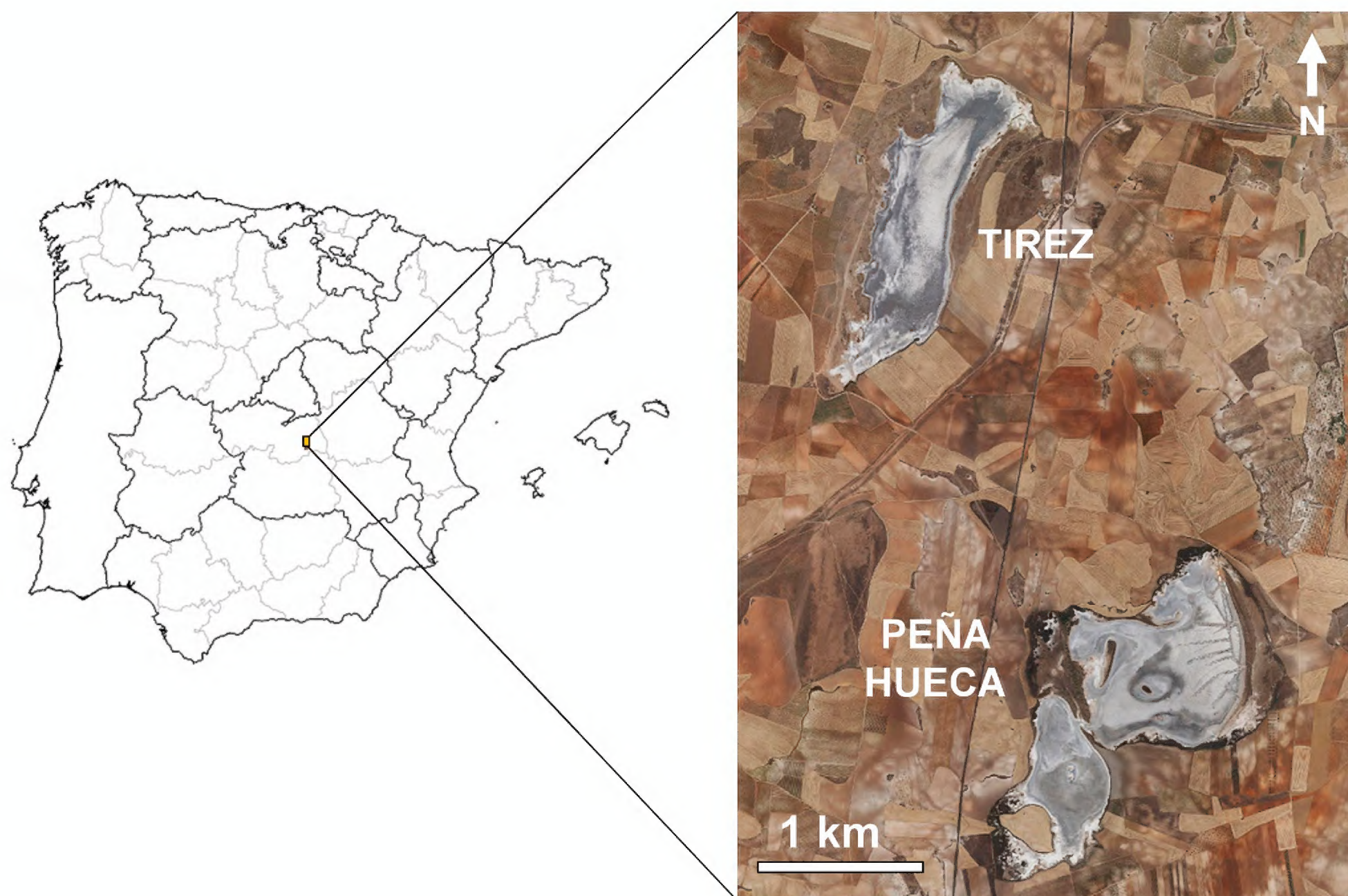


Fig. 1. Map of the study area (Villacañas, Toledo Province, Central Spain) showing the location of the hypersaline lagoons Tirez and Peña Hueca.



Fig. 2. Alkali seepweed prairie (*Suaeda vera*) without grazing, typical habitat of *Mioscirtus wagneri* in the study area (Peña Hueca lagoon, Villacañas, Toledo province, Spain). Photo by P.J. Cordero.



Fig. 3. Male *Mioscirtus wagneri* on alkali seepweed host plant, *Suaeda vera*. Photo by P.J. Cordero.

taking into account the presence/absence of sheep and goat droppings and trying to include areas that have been differentially impacted by grazing. Transects were chosen at random in these areas although we tried to include those with homogeneous vegetation structure along their entire length. Grasshoppers were counted excluding possible repetitions of individuals. Transects were walked as slowly as necessary (2 km/hr) to accurately record the presence and abundance of grasshoppers. Finally, we took pictures of each transect to check plant and soil type cover. As we previously knew the orthopteran communities in these hypersaline areas, and because of the low number of grasshoppers living in salted grounds, we only took into account censuses of *M. wagneri*, discarding other species for analyses. The area and orthopteran communities have been studied since 2005 (P.J. Cordero unpublished). Further, *M. wagneri* is easy to identify *de visu* due to its external appearance, color and hind wing markings. Only *Aiolopus strepens* could be confused with *M. wagneri* beyond a certain distance, but we always took into account this possibility and misidentification was minimal. Capture by hand or netting was unnecessary for identification. Our census of Orthoptera was repeatable and efficient, particularly because the species is well known in the orthopteran community and is easily identifiable (e.g. Gardiner et al. 2005).

We carried out 65 transects in Tirez and 100 transects in Peña Hueca lagoons between 10 and 17 h, during August 2009, the month in which *M. wagneri* is present with 100% adult forms (Cordero et al. 2007b). The data for *M. wagneri* along each transect is summarized by two variables: PRESENCE (presence/absence, 1/0) and ABUNDANCE (number of individuals/m²).

Three percentages of bare soil were considered: brown clay soil not affected by high salt concentration (CLAYED), hypersaline white/grey soil (SALT) and plowed land (PLOWED). Other variables included the percentage cover of the main plant associations in the area. SEEPWEED: formed by the community *Suaeda brevifoliae* described above, with *S. vera* as its most abundant plant species. This small bush is scattered and rarely exceeded 70% ground cover in the study area. It is often associated with other smaller herbaceous species such as *Hordeum marinum*, *Puccinella fasciculata* and, sometimes, *Frankenia thymifolia* and *F. pulverulenta*. HALOPHYTES: heterogeneous grassland associations belonging to halophilic communities, excluding *S. vera*, with plants such as *Sarcocornia perennis*, *Salicornia ramosissima*, *Arthrocnemum coralloides*, *Spergularia media*, *Limonium* spp., *Plantago maritima*, *Suaeda maritima* and some grasses such as *Hordeum marinum*, *Polypogon maritimus*, *Aeluropus littoralis* or *Puccinellia fasciculata* (maximum vegetation cover = 79%). SALSOLA: *Salsola vermiculata* association. The distribution of this plant species is similar to that presented by *S. vera*, however the salinity of the soil may be lower, interspersed with various ruderal species such as *Scolymus* sp., *Bromus* sp., *Centaurea* sp., *Chamaemelum* sp., *Frankenia* sp., etc. (maximum vegetation cover = 80%). ESPARTO: includes formations of *Lygeum spartum* (esparto grass) characterized by dense cover when it is present as the only species (maximum cover = 100%). The accompanying species is usually *Limonium* sp. in moist areas. WHEATGRASS: mainly composed of *Thinopyrum curvifolius* (wheatgrass), of size and structural characteristics similar to ESPARTO, with high ground covering, often with *Juncus* sp. in small amounts (maximum vegetation cover = 80%). HERBACEOUS: several non-halophile ruderal plants including *Phragmites* sp. among others (maximum vegetation cover = 85%). STUBBLE: mown fields of wheat and barley, very close to halophile vegetation plots and rarely including any other ruderal plant species (maximum vegetation

cover = 100%). DROPPINGS: number of individual cylindrical droppings of ovine-goat livestock. We assigned large clusters of faeces composed of a certain number of dropping units (5 to 10 each) according to their size. We used this variable as a surrogate of livestock influence/presence (i.e. grazing impact) and, thus, it is related to cumulative livestock presence in the area (range of droppings abundance between 0 and 7/m²). For analysis, we also recorded the hour (HOUR) when each transect was performed.

Statistical analyses.—We performed a forward stepwise logistic regression in order to analyze the presence of *M. wagneri* (PRESENCE, dependent or response variable) in relation to the cover of the different types of plant species (SEEWEEED, HALOPHYTES, SALSOLA, ESPARTO, WHEATGRASS, HERBACEOUS, and STUBBLE), cover of the different types of bare soil (CLAYED, SALT, and PLOWED) and the number of droppings per transect (DROPPINGS). We also included in the model the hour (HOUR) and the lagoon (LAGOON) of sampling transects. To analyse the abundance of *M. wagneri* (ABUNDANCE), we performed a forward stepwise multiple regression considering the same independent variables as indicated above. Analyses were performed using SPSS v11 (IBM Corp. 2011).

Results

The average abundance of *M. wagneri* in transects with a presence of the species was 0.3 individuals/m² (range 0.05–1.3 individuals/m²). We found that the presence of *M. wagneri* (PRESENCE) was positively related to the cover of *S. vera* (SEEPWEED) (Wald = 40.65, df = 1, $P < 0.0001$; Fig. 4A) but there was no significant association with any other plant community. In turn, dropping abundance (DROPPINGS), the variable indicative of grazing activity, was negatively related to the presence of the grasshopper (Wald = 8.02, df = 1, $P = 0.005$) (Table 1; Fig. 4B). Fig. 4 shows that the probability of the presence of *M. wagneri* in areas with low values of *S. vera* cover is higher without the influence of droppings. For example, at a cover of *S. vera* near 50%, the probability of finding *M. wagneri* without droppings is high (>0.9) whereas with a density of droppings around 7/m² this probability falls down to 0.7. Seemingly, the number of *M. wagneri* per square meter (ABUNDANCE) was also positively related with the cover of *S. vera* (SEEPWEED) ($F = 147.67$, df = 1, $P < 0.001$; Table 2 and Fig. 5A) and sampling time (HOUR) ($F = 8.64$, df = 1, $P = 0.04$). As in the previous analysis, the abundance of *M. wagneri* was negatively associated with the variable indicative of livestock activity (DROPPINGS) ($F = 13.55$, df = 1, $P < 0.001$; Table 2 and Fig. 5B).

Discussion

Our results show the dependence of *M. wagneri* on alkali seepweed formations as expected from a previous observational study (Cordero et al. 2007b). This is coincident with observations from other parts of the species distributional range like North Africa (personal observation). The species feeds and shelters on *S. vera* and mates and buries its oothecae in salted bare soils around the plant. This dependence on a specific microhabitat is probably the reason why *M. wagneri* is particularly sensitive to livestock activity. We found a negative relationship between the presence and abundance of *M. wagneri* in relation to the amount of sheep and goat droppings, and considered this variable as a surrogate of cumulative livestock activities in a particular area. Within the

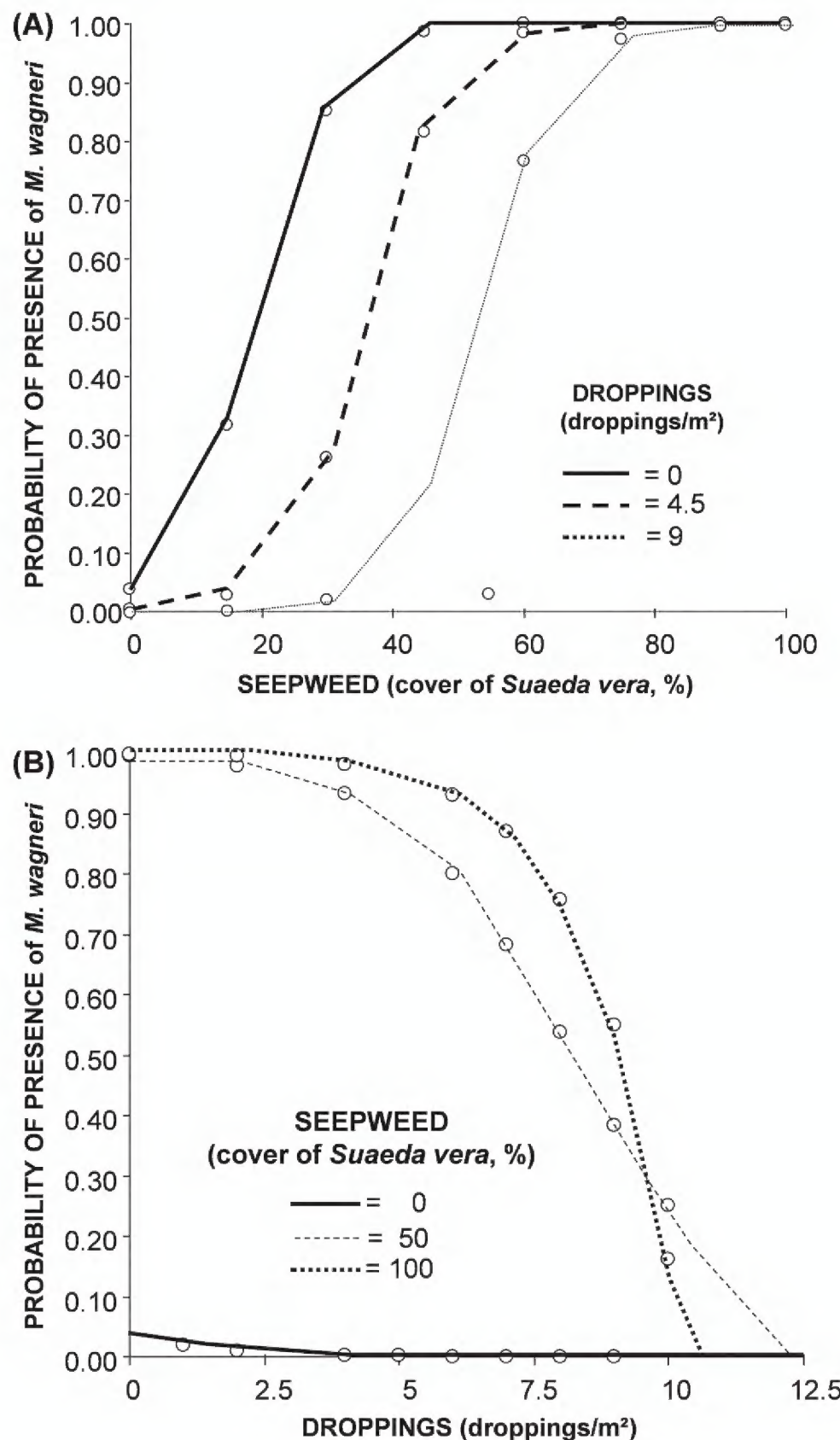


Fig. 4. Relationship between probability of presence of *Mioscirtus wagneri* in the transects (PRESENCE) and A. Cover (%) of *Suaeda vera* (SEEPWEED) for extreme values of livestock droppings per square meter (DROPPINGS), and B. Livestock droppings per square meter (DROPPINGS) for extreme values of cover (%) of *S. vera* (SEEPWEED).

species distributional range, our model predicts the presence and abundance of *M. wagneri* in hypersaline habitats according to different degrees of livestock impact measured as droppings/m². Alkali seepweed plants may coexist with livestock presence, however evident changes occur on a small scale with respect to *M. wagneri* microhabitat (Fig. 2). Alkali seepweed does not seem to be very palatable to sheep and goats, however, under a high concentration of droppings, plants are of lower quality with frequent defoliation and broken branches. This may occur because of livestock activities (trampling, resting over the vegetation, manure, urine or even direct browsing). Abundance of droppings and urine is frequently associated with eutrophic soils. A higher proportion of herbaceous plants like *Hordeum* sp. and *Chenopodium* sp., and

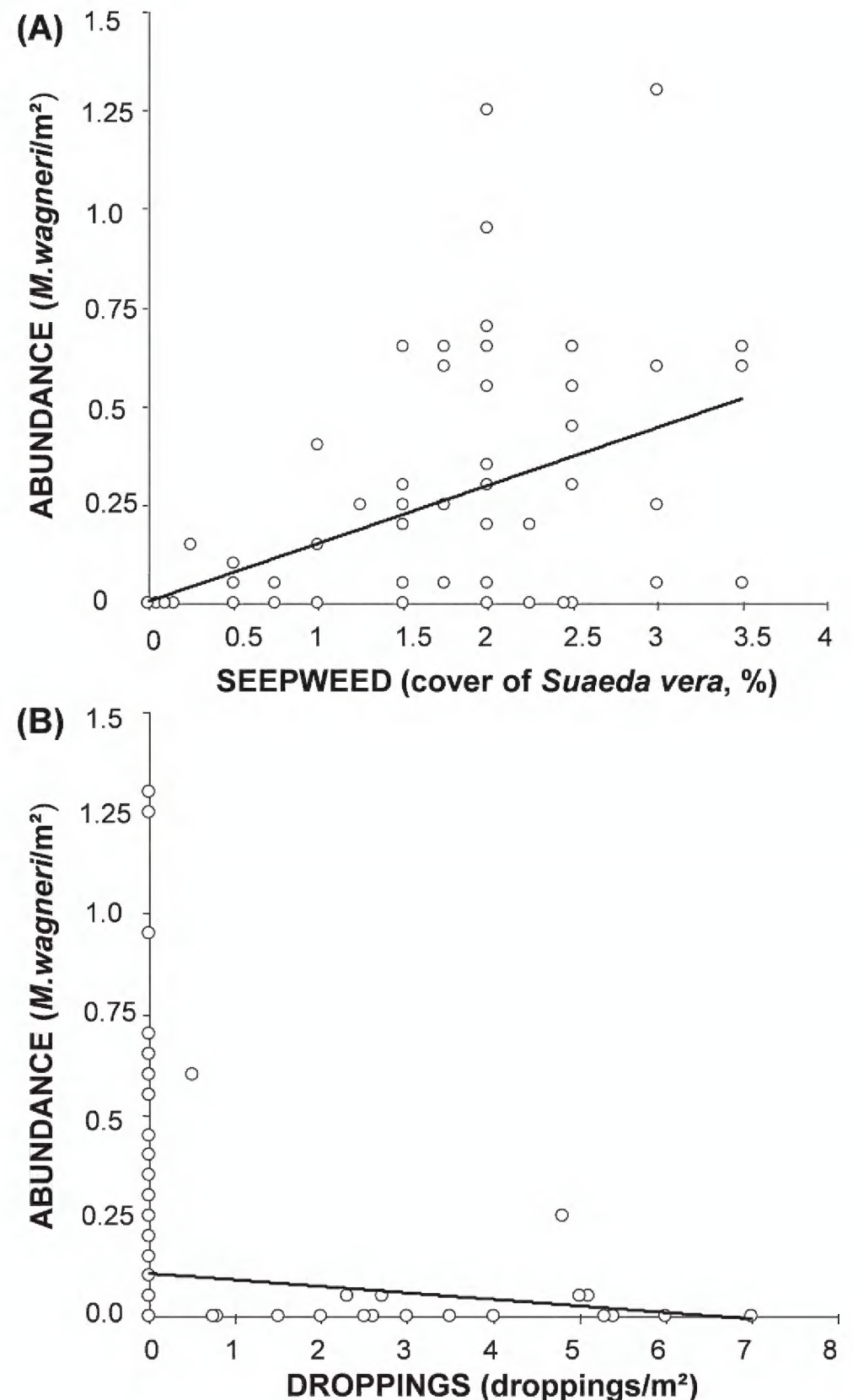


Fig. 5. Relationship between number of *Mioscirtus wagneri* per square meter (ABUNDANCE) and A. Cover (%) of *Suaeda vera* (SEEPWEED), and B. Livestock droppings per square meter (DROPPINGS). Open circles may correspond to one or more overlapping data points.

changes in vegetation composition may increase susceptibility to predation (Joern 2004). Livestock footprints may sink a couple of centimeters into moist salted soils, compacting the ground, modifying its texture, and altering the thin layer of soil above the oothecae, which could compromise egg laying or survival.

Irrespective of the mechanisms involved in the negative relationship between the abundance of droppings and the presence and abundance of *M. wagneri*, our analyses indicate that we can use information on dropping counts as a surrogate of habitat quality for *M. wagneri*. Dropping counts seem to be a measurable and straightforward tool for determining the conservation status and for implementing management measures for preserving the populations of *M. wagneri* and the sensitive hypersaline habitat

Table 1. Results of the forward stepwise logistic regression analysis for presence of *Mioscirtus wagneri* (PRESENCE) in relation to the different explanatory variables analyzed.

	Estimator ± S.E.	Wald	P
<i>Variables included</i>			
Constant	-3.29 ±0.49	45.55	<0.001
SEEPWEED	0.17 ±0.30	40.65	<0.001
DROPPINGS	-0.30 ±0.11	8.02	<0.005
<i>Variables excluded</i>			
HALOPHITES		2.26	0.100
SALSOLA		2.56	0.110
ESPARTO		0.00	0.972
WEATGRASS		0.00	0.996
HERBACEUS		0.74	0.390
CLAYED		3.65	0.056
PLOWED		0.00	0.999
SALT		1.65	0.199
STUBBLE		0.00	0.999
HOUR		1.47	0.225
LAGOON		0.01	0.801

Table 2. Results of the forward stepwise multiple regression analysis for number of *Mioscirtus wagneri*/m² (ABUNDANCE) in relation to the different explanatory variables analyzed.

	Estimator ± S.E.	F	P
<i>Variables included</i>			
Constant	-4.56 ±1.67	7.46	<0.007
SEEPWEED	0.15 ±0.13	147.67	<0.001
DROPPINGS	-0.40 ±0.11	13.55	<0.001
HOUR	9.80 ±3.32	8.64	<0.004
<i>Variables excluded</i>			
HALOPHITES		0.04	0.823
SALSOLA		0.08	0.782
ESPARTO		0.89	0.347
WEATGRASS		0.05	0.817
HERBACEUS		0.17	0.670
CLAYED		2.67	0.104
PLOWED		0.12	0.729
SALT		0.00	0.988
STUBBLE		0.14	0.705
LAGOON		0.69	0.406

where this grasshopper occurs. Dropping counts could help to improve management decisions related to compliance with legislation regarding livestock activities and habitat and species conservation. The estimate of droppings is even more important in our study if we consider that inland hypersaline habitats of *M. wagneri* are, by extension, shared by many macroinvertebrate species of great conservation interest within territories of high conservation concern. These include rare and fragmented taxa adapted to salinity, endemics dependent on salted soils, halophilous vegetation, or terrestrial steppic macroinvertebrates that find refuge from agriculture in these hypersaline ecosystems (Williams 1973, Ribera and Blasco-Zumeta 1998, Ribera 2000, Martín-Herrero et al. 2003, Abellán et al. 2005, Cordero et al. 2007a, Cordero and Llorente 2008, Pichaco-García and Ramos 2016).

We highly recommend the use of electric shepherd fencing around all sensitive and protected areas where inland hypersaline ecosystems are present in order to deter livestock. We also recommend intensive educational campaigns for farm owners and shepherds, showing the ecological importance of these singular and unique habitats for rare and exclusive species of plants and invertebrates.

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